TÜBİTAK

Turkish Journal of Engineering & Environmental Sciences

http://journals.tubitak.gov.tr/engineering/

Research Article

Turkish J Eng Env Sci
(2013) 37: 109 – 122

doi:10.3906/muh-1207-21

Gamma radioactivity measurements in Nile River sediment samples

Shams ISSA*, **Mohamed UOSIF**, **Reda ELSAMAN**
Physics Department, Faculty of Science, Al-Azhar University, Assiut, Egypt

Received: 28.07.2012 • **Accepted:** 30.11.2012 • **Published Online:** 04.03.2013 • **Printed:** 01.04.2013

Abstract: River sediment depositions on the bottom of rivers most frequently consist of sand and gravel particles with different grain sizes, which make them particularly valuable for building construction. Knowledge of the radioactivity present in building materials enables one to assess any possible radiological hazard to humankind by the use of such materials. A total of 69 Nile River sediment samples from 8 cities and 24 locations were collected along a 139-km area in Minia, Egypt. The radiological hazards were calculated for the investigated area. The results of the study could serve as important baseline radiometric data for future epidemiological studies and monitoring initiatives in the study area.

Key words: Natural radionuclide, Nile River, sediment and radiological implications

1. Introduction

Everyone on the planet is exposed to some background level of radiation. Human exposure to ionizing radiation is one of the scientific subjects that attract public attention, since radiation of natural origin is responsible for most of the total radiation exposure of the human population (UNSCEAR, 2000). Natural radioactivity is widespread in the earth's environment and it exists in various geological formations like soils, rocks, plants, sand, water, and air. Hence, humans should be aware of their natural environment with regard to the radiation effects due to the naturally occurring and induced radioactive elements. Long-term exposure to uranium and radium through inhalation has several health effects such as chronic lung diseases, acute leucopoenia, anemia, and necrosis of the mouth. Radium causes bone, cranial, and nasal tumors. Thorium exposure can cause lung, pancreas, hepatic, bone, and kidney cancers and leukemia (Taskin et al., 2009). Knowledge about the distribution of radioactivity present in natural materials enables one to assess any possible radiological hazard to humankind by the use of such materials.

The Nile River has supported many civilizations of Egypt throughout history and continues to play a vital role in supplying precious water for drinking, irrigation, and industry to the people of the Egyptian state of Minia. The Nile River plays an essential role in Egyptian life; it was the lifeline of Egypt, the study of the natural radioactivity of the sediments from its banks is very important, and the assessment of natural dose rates will be of some interest to regional health. The Nile is a major north-flowing river in northeastern Africa, generally regarded as the longest river in the world. It is 6650 km long. It runs through the 10 countries of Sudan, South Sudan, Burundi, Rwanda, the Democratic Republic of the Congo, Tanzania, Kenya, Ethiopia, Uganda, and Egypt.

During the last decades, there has been an increasing interest in the study of radioactivity in Nile River sediment (El-Gamal et al., 2007; Uosif, 2007; Dawood, 2010)

---

*Correspondence: shams_issa@yahoo.com

2. Materials and methods

2.1. Study area

The present study covered an area in the Minia governorate from Deir Mawas (38°37′34″N; 30°98′03″E) to Maghagha (38°28′39″N; 30°83′32″E), about 139 km, and included 8 districts: Deir Mawas (4 samples), Mallawi (12 samples), Abu-Qurqas (9 samples), Minia (14 samples), Samalott (4 samples), Mattay (3 samples), Beni-Mazar (12 samples), and Maghagha (12 samples) (Figure). The Minia governorate is one of the important agricultural and industrial regions in Egypt. Minia is mainly an agricultural governorate, as it has around 6% of the total agricultural lands in Egypt, producing cotton, wheat, corn, and potatoes. In addition, it is home to several industrial activities including textile and weaving, packing and freezing vegetables, fish farming, and several other activities. Therefore, the Nile River is the lifeline of the Minia governorate.

2.2. Sample collection and preparation

The present study area of the Nile River in Minia covered a total length of 139 km, from which 8 successive cities and 24 locations were selected. The samples (100 cm in depth) were collected from Minia between May 2010 and June 2011. The recently deposited sediment samples were manually collected with the help of a plastic spade in polyethylene bags. Sediment samples were oven dried at a temperature of 110 °C for 12 h and sieved through 200 mesh. The dried samples were transferred to polyethylene Marinelli beakers of 350-cm^3 capacity. Each sediment sample was left for at least 4 weeks to reach secular equilibrium between the radium and thorium and their progenies (ASTM, 1983, 1986).

2.3. Gamma spectrometric analysis

Activity measurements have been performed by gamma-ray spectrometer, employing a scintillation detector (7.62 × 7.62 cm). It had a hermetically sealed assembly, which included a NaI (Tl) crystal, coupled with a PC-MCA Canberra Accuspec. To reduce the gamma-ray background, a cylindrical lead shield (100 mm thick) with a fixed bottom and movable cover shielded the detector. The lead shield contained an inner concentric cylinder of copper (0.3 mm thick) in order to absorb X-rays generated in the lead. In order to determine the background distribution in the environment around the detector, an empty sealed beaker was counted in the same manner and in the same geometry as the samples. The measurement time of the activity or background was 43,200 s. The background spectra were used to correct the net peak area of the gamma rays of the measured isotopes. A dedicated software program was used (Genie-2000, 1997).

The ^{226}Ra radionuclide was estimated from the 351.9 keV (36.7%) γ-peak of ^{214}Pb, and 609.3 keV (46.1%), 1120.3 keV (15%), 1728.6 keV (3.05%), and 1764 keV (15.9%) γ-peak of ^{214}Bi. The 186 keV photon peak of ^{226}Ra was not used because of the interfering peak of ^{235}U, with an energy of 185.7 keV. The ^{232}Th radionuclide was estimated from the 911.2 keV (29%) γ-peak of ^{228}Ac and the 238.6 keV (43.6%) γ-peak of ^{212}Pb. The ^{40}K radionuclide was estimated using the 1461 keV (10.7%) γ-peak from ^{40}K itself. The below detectable limits (DLs) were 25.2 Bq kg^{-1} for ^{40}K, 6.5 Bq kg^{-1} for ^{226}Ra, and 5.7 Bq kg^{-1} for ^{232}Th (Issa et al., 2012).

3. Results and discussion

3.1. Radioactivity analysis

The distribution of the detected radionuclides, ^{226}Ra, ^{232}Th, and ^{40}K, in the sediment samples are shown in Table 1. The average activity concentrations varied from location to location, because the river bottom can

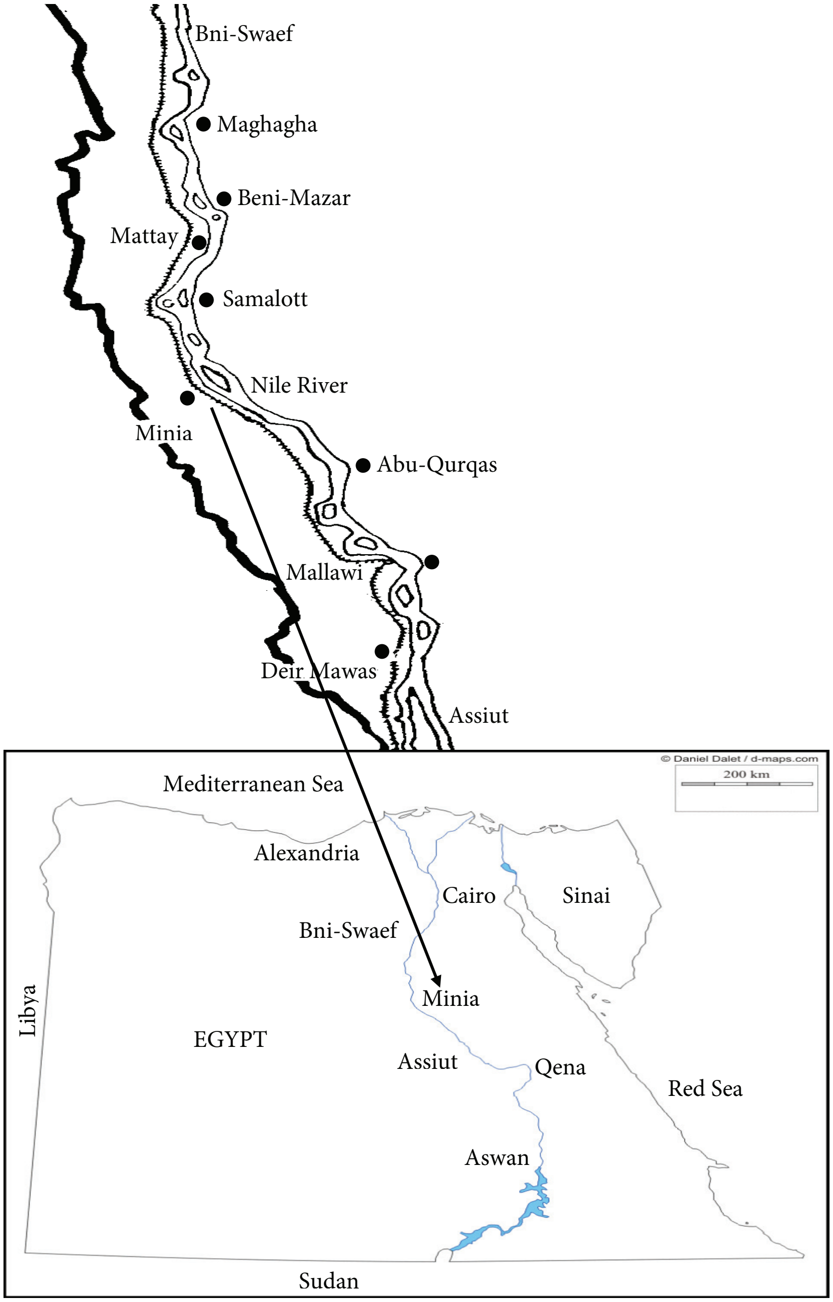

Figure. Location of the Nile River with experimental sites in Minia.

exhibit large variations in chemical and mineralogical properties and rare-earth elements (Ramasamy et al., 2011). The ^{40}K activity concentration dominated over that of the ^{226}Ra and ^{232}Th elemental activities, as normally happens in soil.

The highest average concentrations of ^{226}Ra and ^{40}K were found in Mattay, and that of ^{232}Th was found in Minia, whereas the lowest average concentrations of ^{226}Ra and ^{232}Th were found in Mallawi and that of ^{40}K

Table 1. Activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the sediment samples.

Location	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Maghagha			
Sharona	25 ± 1.3	13 ± 0.6	210 ± 10.5
	38 ± 1.9	12 ± 0.6	245 ± 12.2
	23 ± 1.6	15 ± 0.7	282 ± 14
Alsaida	41 ± 1.2	65 ± 3.2	322 ± 16.1
	24 ± 2.6	24 ± 3.2	358 ± 17.9
	37 ± 1.9	7 ± 0.4	171 ± 8.6
Jazert Sharona	147 ± 8	157 ± 8	400 ± 20
	14 ± 1.1	9 ± 1.1	163 ± 10
	17 ± 0.8	4 ± 0.2	230 ± 11.5
Tarat Alnile	36 ± 1.8	17 ± 0.8	275 ± 13.7
	45 ± 4.4	100 ± 5	246 ± 12.3
	10 ± 1.3	6 ± 1	64 ± 3.2
Average	38.1 ± 2.3	35.8 ± 2.1	247 ± 13
Range	(10 ± 1.3)–(147 ± 8)	(4 ± 0.2)–(157 ± 8)	(64 ± 3.2)–(400 ± 20)
Beni-Mazar			
Beni Mazar Algadeda	82 ± 4.1	78 ± 3.9	314 ± 15.7
	12 ± 1.2	94 ± 5	302 ± 15.1
	19 ± 1.8	12 ± 1.9	274 ± 13.7
Beni Samet	34 ± 1.7	55 ± 2.7	205 ± 10.3
	22 ± 1.1	13 ± 0.7	235 ± 11.7
	83 ± 4	58 ± 2.9	378 ± 18.9
Almtatora	21 ± 3.2	6 ± 0.9	157 ± 7.9
	12 ± 0.6	8 ± 0.4	31 ± 1.6
	20 ± 1.6	13 ± 2.2	265 ± 14.3
Elsalam	31 ± 3.1	17 ± 2.4	229 ± 13.2
	45 ± 2.2	52 ± 2.6	274 ± 13.7
	24 ± 2.3	15 ± 2.0	424 ± 21
Average	33.8 ± 2.3	35.1 ± 2.3	257.3 ± 13
Range	(12 ± 0.6)–(83 ± 4)	(6 ± 0.9)–(94 ± 5)	(31 ± 1.6)–(424 ± 21)
Mattay			
Ali Basha	95 ± 4.7	64 ± 3.2	463 ± 23.2
	31 ± 1.5	18 ± 0.9	262 ± 13
	146 ± 8	8 ± 0.6	424 ± 21
Average	90.7 ± 4.5	30 ± 3	383 ± 19
Range	(31 ± 1.5)–(146 ± 8)	(8 ± 0.6)–(64 ± 3.2)	(262 ± 13)–(436 ± 23)
Samalott			
Jabal altair	25 ± 1.2	33 ± 1.7	197 ± 10
	7 ± 0.2	12 ± 0.1	200 ± 10
	69 ± 3.4	59 ± 3	355 ± 18
Arab alzena	30 ± 2.4	29 ± 2.6	214 ± 11.7
Average	32.8 ± 1.8	33.3 ± 1.9	242 ± 12
Range	(7 ± 0.2)–(69± 3.4)	(0.2 ± 0.1)–(33± 1.7)	(197 ± 10)–(355 ± 18)
Minia			
Kedwan	113 ± 6.7	117 ± 6	227 ± 11.4
	67 ± 3.4	91 ± 4.5	337 ± 16.8
	49 ± 2.5	50 ± 2.5	241 ± 12.1

Table 1. Continued.

Location	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Elhawarta	40 ± 3.1	12.5 ± 0.6	47 ± 6.9
	17 ± 1.9	23 ± 1.2	412 ± 20.6
	12 ± 0.8	11 ± 0.6	47 ± 4.5
Ard Sultan	24 ± 2.7	19 ± 2.3	239 ± 13.5
	32 ± 1.9	49 ± 3.7	226 ± 11.3
Abu Flow	24 ± 2.1	8 ± 0.3	240 ± 14.2
	7 ± 1.4	8 ± 1.3	122 ± 10.1
	188 ± 10	9 ± 0.3	412 ± 45
Zohrt Elporgi	25 ± 3.6	38 ± 3.1	274 ± 16.6
	66 ± 3.3	99 ± 4.9	324 ± 16.2
	44 ± 3.2	43 ± 2.1	251 ± 12.6
Average	50.6 ± 3.3	41.3 ± 2.4	242.8 ± 15
Range	(7 ± 1.7)–(188 ± 10)	(8 ± 0.3)–(117 ± 6)	(47 ± 6.9)–(412 ± 45)
Abu-Qurqas			
Meken	17 ± 0.2	13 ± 1.4	217 ± 11.7
	10 ± 1	12 ± 1	168 ± 9.1
	24 ± 1.2	12 ± 0.7	195 ± 10.8
Beni Mohamed	36 ± 1.8	78 ± 4	173 ± 8.7
	29 ± 2.3	19 ± 2.3	315 ± 17.2
	19 ± 1.9	6 ± 0.7	131 ± 8
Beni Hassan	38 ± 1.8	13 ± 0.7	241 ± 12
	92 ± 5	57 ± 2.8	331 ± 17
	33 ± 1.6	27 ± 1.4	231 ± 11.6
Average	33.1 ± 1.8	26.3 ± 1.7	222.4 ± 11.7
Range	(10 ± 1)–(92 ± 5)	(6 ± 0.7)–(78 ± 4)	(131 ± 8)–(331 ± 17)
Mallawi			
Elroda	21 ± 1.9	16 ± 1.6	147 ± 8
	16 ± 1.4	13 ± 1.1	329 ± 18
	16 ± 0.8	12 ± 0.6	195 ± 9.8
Almasara	31 ± 1.3	20 ± 1.9	187 ± 10.4
	119 ± 6	30 ± 3.2	230 ± 11.5
	27 ± 2.8	38 ± 3.2	231 ± 11.6
Kalando	35 ± 3.5	14 ± 1.5	231 ± 13
	15 ± 1.8	28 ± 3.2	250 ± 14.3
	19 ± 1	27 ± 1.3	188 ± 9.4
Shark Elmadena	27 ± 1.3	13 ± 0.6	227 ± 11.3
	24 ± 1.2	14 ± 0.7	252 ± 12.6
	28 ± 2.7	18 ± 0.9	247 ± 12.4
Average	31.5 ± 2.1	20.3 ± 1.7	226.2 ± 11.8
Range	(15 ± 1.8)–(119 ± 6)	(12 ± 0.6)–(38 ± 3.2)	(147 ± 8)–(329 ± 18)
Deir Mawas			
Alrahmanya	25 ± 4.5	12 ± 1.4	193 ± 10
	67 ± 5.9	18 ± 3	292 ± 18
	102 ± 5.1	80 ± 9.0	194 ± 9.7
Average	64.7 ± 5.2	36.7 ± 4.5	226.3 ± 12
Range	(25 ± 4.5)–(102 ± 5.1)	(12 ± 1.4)–(80 ± 9)	(193 ± 10)–(292 ± 18)

was found in Samalott. The worldwide average concentrations of the radionuclides ^{226}Ra, ^{232}Th, and ^{40}K, reported by UNSCEAR (2000), are 35, 30, and 400 Bq kg^{-1}, respectively. Our results show that the average activity concentrations of ^{40}K in our samples are comparable with the worldwide concentrations. The average activity concentration of ^{226}Ra in Mattay, Minia, and Deir Mawas was higher than the reported international average (UNSCEAR, 2000). The average activity concentration of ^{232}Th in Maghagha, Beni-Mazar, Samalott, Minia, and Deir Mawas was higher than the reported international average (UNSCEAR, 2000). Table 2 shows a comparison of the radioactivity concentrations in the sediments with other areas of the world.

Table 2. Comparison of the activity concentrations of the Nile River sediment in Minia with other countries.

Region	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	References
Greece	22.6	24.5	497	Papaefthymiou et al. (2007)
Egypt	24.6	31.4	427.5	El Mamoney and Khater (2004)
Algeria	-	6.5–31.7	55.9–607.4	Benamar et al. (1997)
Iran	-	26	395	Abdi et al. (2008)
Spain	41–2939	12–63	-	Lozano et al. (2002)
Turkey	15–116	17–87	51–1605	Kurnaz et al. (2007)

3.2. Evaluation of radiological hazard effects

3.2.1. Absorbed dose rate

Calculating the absorbed dose rate is the first major step for evaluating the health risk. With regard to biological effects, the radiological and clinical effects are directly related to the absorbed dose rate (Ramasamy et al., 2011). The measured activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are converted into doses by applying the conversion factors 0.462, 0.604, and 0.0417 for uranium, thorium, and potassium, respectively (UNSCEAR, 2000). These factors are used to calculate the total dose rate (D) (nGy h^{-1}) using the following equation:

$$D = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K(nGy\ h^{-1}),$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K in the river sediments, respectively. The calculated values for the samples are presented in Table 3. The average absorbed dose rate for the sediment samples in Maghagha, Beni-Mazar, Samalott, Abu-Qurqas, and Mallawi was lower than the world average value (57 nGy h^{-1}) (UNSCEAR, 2000). The average absorbed dose rate for sediment samples in Mattay, Minia, and Deir Mawas was higher than the world average value (57 nGy h^{-1}) (UNSCEAR, 2000). Table 2 reports that the highest average value of the dose rate was found in Mattay.

3.2.2. The annual effective dose equivalent

Annual estimated average effective dose equivalent (AEDE) received by an individual was calculated using a conversion factor of 0.7 Sv Gy^{-1}, which was used to convert the absorbed rate to the human effective dose equivalent with an outdoor occupancy of 20% and 80% for indoors (UNSCEAR, 1993). The annual effective dose is determined using the following equations:

$$\text{AEDE (outdoor) } (\mu\text{Sv year}^{-1}) = \text{absorbed dose (nGy h}^{-1}) \times 8760\text{ h} \times 0.7\text{ Sv Gy}^{-1} \times 0.2 \times 10^{-3},$$

$$\text{AEDE (indoor) } (\mu\text{Sv year}^{-1}) = \text{absorbed dose (nGy h}^{-1}) \times 8760\text{ h} \times 0.7\text{ Sv Gy}^{-1} \times 0.8 \times 10^{-3}.$$

In Table 3 we can observe the calculated minimum and maximum values of the AEDE for the investigated locations. The average indoor AEDE values for the sediment samples were lower than the world average values at 450 μSv year^{-1} (Örgün et al., 2007). The average outdoor AEDE values for the sediment samples in Mattay, Minia, and Deir Mawas were higher than the world average values at 70 μSv year^{-1} (Örgün et al., 2007), where the outdoor AEDEs do exceed the world average due to the presence of the high activity concentration of ^{232}Th and ^{40}K.

Table 3. Dose rates, AEDE (indoor and outdoor), and Ra$_{eq}$.

Location	Dose rates (nGy h^{-1})	AEDE (μSv year^{-1}) Outdoor	Indoor	Ra$_{eq}$ (Bq kg^{-1})
Maghagha				
Sharona	28.2	34.2	138.1	59.8
	35.0	42.5	171.8	74.0
	31.4	38.2	154.3	66.2
Alsaida	71.6	86.9	351.4	158.7
	40.5	49.2	198.7	85.9
	28.5	34.5	139.6	60.2
Jazert Sharona	179.4	217.8	880.2	402
	18.7	22.7	91.7	39.4
	19.9	24.1	97.4	40.4
Tarat Alnile	38.4	46.6	188.2	81.5
	91.4	111.0	448.6	206.9
	10.9	13.2	53.5	23.5
Average	49.5	60.1	242.8	108
Range	10.9–179.4	13.2–217.8	53.5–880.2	23.5–402
Beni-Mazar				
Beni Mazar Algadeda	98.1	119.1	481.2	218
	74.9	90.9	367.5	169.7
	27.5	33.3	134.7	57.3
Beni Samet	57.5	69.8	282.0	128.4
	27.8	33.8	136.5	58.7
	89.1	108.2	437.3	195.0
Almtatora	19.9	24.1	97.5	41.7
	11.7	14.2	57.2	26
	28.1	34.2	138.1	59.0
Elsalam	34.1	41.4	167.5	72.9
	63.6	77.2	312.1	140.5
	37.8	45.9	185.6	78.1
Average	47.5	57.7	233	104
Range	11.7–98.1	14.2–119.1	57.2–481.2	26–218
Mattay				
Ali Basha	102	124	500	222
	36.1	43.8	177	77
	90.0	109.2	441.3	190.1
Average	76.0	92.2	372.7	163
Range	36.1–102	43.8–124	177–500	77–222
Samalott				
Jabal altair	39.7	48.2	194.7	87.4

Table 3. Continued.

Location	Dose rates (nGy h^{-1})	AEDE (μSv $year^{-1}$)		Ra_{eq} (Bq kg^{-1})
		Outdoor	Indoor	
	40.3	48.9	197.7	87.9
	82.3	99.9	404	181
Arab alzena	40.3	48.9	197.7	87.9
Average	43.0	52.2	211	94
Range	9.8–82.3	12–99.9	48.3–404	87.4–181
Minia				
Kedwan	132	161	649	298
	100.0	121.3	490.4	223.1
	62.9	76.3	308.5	139.1
Elhawarta	28.0	34.0	137.3	61.5
	38.9	47.2	191.0	81.6
	14.1	17.2	69.4	31.3
Ard Sultan	32.5	39.5	159.6	69.6
	53.8	65.3	263.9	119.5
Abu Flow	25.9	31.5	127.2	53.9
	13.2	16	64.5	28
	109.5	132.9	537	232.6
Zohrt Elporgi	45.9	55.7	225.3	100.4
	103.8	126.0	509.2	232.5
	56.8	68.9	278.5	124.8
Average	58.4	70.9	286.5	128.3
Range	13.2–132	16–161	64.5–649	28–298
Abu-Qurqas				
Meken	24.8	30.0	121.4	52.3
	18.9	22.9	92.6	40.1
	26.5	32.1	129.8	56.2
Beni Mohamed	71.0	86.1	348.1	160.9
	38.0	46.1	186.5	80.4
	17.9	21.7	87.6	37.7
Beni Hassan	35.5	43.0	173.9	75.1
	91	110	445	199.0
	41.2	50.0	202.0	89.4
Average	40.5	49.1	198	88
Range	17.9–91	21.7–110	87.6–445	37.7–199
Mallawi				
Elroda	25.5	30.9	125.1	55.2
	29.0	35.2	142.1	59.9
	22.8	27.6	111.7	48.2
Almasara	34.2	41.5	167.8	74.0
	82.7	100.4	406	178
	45.1	54.7	221.0	99.1
Kalando	34.3	41.6	168.1	72.8
	34.3	41.6	168.1	74.3
	32.9	40.0	161.5	72.1
Shark Elmadena	29.8	36.2	146.1	63.1
	30.1	36.5	147.4	63.4
	34.1	41.4	167.3	72.8

Table 3. Continued.

Location	Dose rates (nGy h^{-1})	AEDE (μSv $year^{-1}$)		Ra_{eq} (Bq kg^{-1})
		Outdoor	Indoor	
Average	36.2	44.0	178	78
Range	22.8–82.7	27.6–100.4	111.7–406	48.2–178
Deir Mawas				
Alrahmanya	26.8	32.6	131.7	57.0
	54.0	65.5	264.9	115.2
	104	126	508	231
Average	61.5	74.6	301.5	134.5
Range	26.8–104	32.6–126	131.7–508	57–231

3.2.3. Radium equivalent activities

The results were evaluated in terms of the radiation hazard by means of the Ra equivalent activity (Ra_{eq}). Ra_{eq} is a widely used hazard index and it is calculated through the relation given by Beretka and Mathew (1985). It is assumed that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K produce the same gamma-ray dose rate:

$$Ra_{eq}(Bqkg^{-1}) = C_{Ra} + 1.43C_{Th} + 0.077C_K,$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The range of Ra_{eq} was estimated for the collected samples and is given in Table 3. The estimated average values were lower than the recommended maximum value of 370 Bq kg^{-1} for the safe use of materials in the construction of buildings (UNSCEAR, 2000), because of the leaching of heavy minerals by the continuous flow of water in the river (Ramasamy et al., 2011).

3.2.4. Hazard indices

Beretka and Mathew (1985) defined 2 indices that represent external and internal radiation hazards. The prime objective of these indices is to limit the radiation dose to a dose equivalent limit of 1 mSv $year^{-1}$. The external hazard index (H_{ex}) is calculated using the given equation:

$$H_{ex} = (C_{Ra}/370 + C_{Th}/259 + C_K/4810) \leq 1,$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The H_{ex} must not exceed the limit of unity for the radiation hazard to be negligible. On the other hand, the internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and its short-lived progeny (Ramasamy et al., 2011), and it is given by the following formula (Beretka and Mathew, 1985; Örgün et al., 2007):

$$H_{in} = (C_{Ra}/185 + C_{Th}/259 + C_K/4810) \leq 1,$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The value of H_{in} must also be less than unity to have negligible hazardous effects of radon and its short-lived progeny to the respiratory organs (UNSCEAR, 2000). Table 4 shows that the calculated average values of hazard indices for all samples are less than unity.

Table 4. Hazard indices (H_{ex}, H_{in}, I_γ, ELCR, and AGDE) for investigated samples.

Location	Hazard indices			
	H_{ex}	H_{in}	I_γ (mSv year^{-1})	AGDE
Maghagha				
Sharona	0.2	0.2	0.2	197.5
	0.2	0.3	0.3	244.5
	0.2	0.2	0.2	222.3
Alsaida	0.4	0.5	0.6	499.5
	0.2	0.3	0.3	286.9
	0.2	0.3	0.2	197.3
Jazert Sharona	1.1	1.5	1.4	1236
	0.1	0.1	0.1	132.1
	0.1	0.2	0.2	141.5
Tarat Alnile	0.2	0.3	0.3	268.7
	0.6	0.7	0.7	634.3
	0.1	0.1	0.1	76.1
Average	0.3	0.4	0.4	344.7
Range	0.1–1.1	0.1–1.5	0.1–1.4	76.1–1236
Beni-Mazar				
Beni Mazar Algadeda	0.6	0.8	0.8	678.0
	0.5	0.5	0.6	524.8
	0.2	0.2	0.2	194.9
Beni Samet	0.3	0.4	0.5	399.3
	0.2	0.2	0.2	196.1
	0.5	0.8	0.7	617.6
Almtatora	0.1	0.2	0.2	139.3
	0.1	0.1	0.1	80.3
	0.2	0.2	0.2	199.4
Elsalam	0.2	0.3	0.3	238.8
	0.4	0.5	0.5	442.4
	0.2	0.3	0.3	270.0
Average	0.3	0.4	0.4	331.7
Range	0.1–0.6	0.1–0.8	0.1–0.8	80.3–678
Mattay				
Ali Basha	0.6	0.9	0.8	707
	0.2	0.3	0.3	253
	0.5	0.9	0.7	617.7
Average	0.4	0.7	0.6	525.8
Range	0.2–0.6	0.3–0.9	0.3–0.8	253–707
Samalott				
Jabal altair	0.2	0.3	0.3	277.0
	0.2	0.3	0.3	281.8
	0.5	0.7	0.6	571
Arab alzena	0.2	0.3	0.3	281.1
Average	0.3	0.4	0.4	352.8
Range	0.2–0.5	0.3–0.7	0.3–0.6	277–571
Minia				
Kedwan	0.8	1.1	1.0	910
	0.6	0.8	0.8	693.2

Table 4. Continued.

Location	Hazard indices			
	H_{ex}	H_{in}	I_γ (mSv year^{-1})	AGDE
	0.4	0.5	0.5	436.1
Elhawarta	0.2	0.3	0.2	190.6
	0.2	0.3	0.3	278.0
	0.1	0.1	0.1	97.8
Ard Sultan	0.2	0.3	0.3	228.6
	0.3	0.4	0.4	374.7
Abu Flow	0.1	0.2	0.2	188
	0.1	0.1	0.1	93.4
	0.6	1.1	0.8	747.9
Zohrt Elporgi	0.3	0.3	0.4	322.1
	0.6	0.8	0.8	719.5
	0.3	0.5	0.4	394.5
Average	0.3	0.5	0.5	409.5
Range	0.1–0.8	0.1–1.1	0.1–1.0	93.4–910
Abu-Qurqas				
Meken	0.1	0.2	0.2	175.0
	0.1	0.1	0.1	133.8
	0.2	0.2	0.2	185.6
Beni Mohamed	0.4	0.5	0.6	491.6
	0.2	0.3	0.3	267.9
	0.1	0.2	0.1	125
Beni Hassan	0.2	0.3	0.3	247.4
	0.5	0.8	0.7	627
	0.2	0.3	0.3	287.4
Average	0.2	0.3	0.3	282
Range	0.1–0.5	0.1–0.8	0.1–0.7	125–627
Mallawi				
Elroda	0.1	0.2	0.2	177.9
	0.2	0.2	0.2	207.1
	0.1	0.2	0.2	161
Almasara	0.2	0.3	0.3	238.1
	0.5	0.8	0.6	565
	0.3	0.3	0.4	314.8
Kalando	0.2	0.3	0.3	239.2
	0.2	0.2	0.3	241.9
	0.2	0.2	0.3	230.6
Shark Elmadena	0.2	0.2	0.2	209.0
	0.2	0.2	0.2	211.8
	0.2	0.3	0.3	239.3
Average	0.2	0.3	0.3	253.0
Range	0.1–0.5	0.2–0.8	0.2–0.6	161–565
Deir Mawas				
Alrahmanya	0.2	0.2	0.2	188.0
	0.3	0.5	0.4	374.0
	0.6	0.9	0.8	711
Average	0.4	0.5	0.5	424
Range	0.2–0.6	0.2–0.9	0.2–0.8	188–711

3.2.5. Gamma index

Another radiation hazard, called the gamma activity concentration index (I_γ), has been defined by the European Commission (EC, 1999), (Righi and Bruzzi, 2006) and it is given below.

$$I_\gamma = (C_{Ra}/300 + C_{Th}/200 + C_K/3000),$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The I_γ is correlated with the annual dose rate due to the excess external gamma radiation caused by superficial material. Values of I_γ of ≤ 2 correspond to a dose rate criterion of 0.3 mSv year^{-1}, whereas $I_\gamma \leq 6$ corresponds to a criterion of 1 mSv year^{-1} (EC, 1999; Anjos, 2005). Thus, I_γ should be used only as a screening tool for identifying materials that might be of concern to be used as construction materials, though materials with I_γ >6 should be avoided (Ravisankar et al., 2012) since these values correspond to dose rates higher than 1 mSv year^{-1} (EC, 1999), which is the highest value of the dose rates recommended for humans (UNSCEAR, 2000).

The distribution of the values of I_γ for the Nile River sediment used as the building material analyzed in this work is presented in Table 4. The average I_γ in the sediment samples varied between 0.3 and 0.6. All of the I_γ values were <1. Therefore, the annual effective dose delivered by the sediment samples was smaller than the annual effective dose constraint of 1 mSv year^{-1}. Hence, these building materials can be exempted from all of the restriction concerning radioactivity.

3.2.6. Annual gonadal dose equivalent

The bone marrow activity and the bone surface cells are considered as organs of interest by UNSCEAR (1988). Therefore, the annual gonadal dose equivalent (AGDE) due to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K was calculated using the following formula (Mamont-Ciesla et al., 1982):

$$\text{AGDE } (\mu\text{Sv year}^{-1}) = 3.09\ C_{Ra} + 4.18\ C_{Th} + 0.314\ C_K.$$

The obtained AGDE values are listed in Table 4. The average AGDE values varied from 253 to 525.8 μSv year^{-1}. Table 4 shows that the highest average AGDE value was 525.8 μSv year^{-1}, in Mattay.

4. Conclusion

The activity levels and distribution of the natural terrestrial radionuclides of ^{226}Ra, ^{232}Th, and ^{40}K were measured using a gamma-ray spectrometry system for the Nile River sediment samples collected from Minia in Egypt. The extracted values were, in general, comparable to the corresponding ones obtained from other countries, and they all fell within the average worldwide ranges shown in Table 2. From the measured values, the average values of the absorbed dose rate in air, Ra_{eq}, H_{ex} and H_{in}, and AGDE and AEDE (outdoor and indoor) were calculated. The Ra_{eq}, H_{ex} and H_{in}, and AGDE were calculated to assess the radiological hazard of sand mixed with the sediment, since sand is used as construction material in this region. This study can be used as a baseline for future investigations and the data obtained in this study may be useful for natural radioactivity mapping. It seems necessary to determine the radioactivity concentrations in the Nile River sediments in other parts of Egypt. The results may also be used as reference data for monitoring possible radioactivity pollution in future.

Acknowledgments

This work was carried out using the nuclear analytical facilities at the Physics Department of the Faculty of Sciences, Al-Azhar University, Assiut, Egypt.

References

Abdi, M.R., Kamali, M. and Vaezifar, S., "Distribution of Radioactive Pollution of 238U, 232Th, 40K and 137Cs in Northwestern Coasts of Persian Gulf, Iran", Marine Pollution Bulletin, 56, 751–757, 2008.

American Society for Testing Materials, "Standard Method for Sampling Surface Soils for Radionuclides", ASTM Report No. C, 983, 1983.

American Society for Testing Materials, "Recommended Practice for Investigation and Sampling Soil and Rock for Engineering Purposes", ASTM Report No. D, 109, 1986.

Anjos, R.M., "Natural Radionuclide Distribution in Brazilian Commercial Granites", Radiation Measurements, 39, 245–253, 2005.

Benamar, M.A., Zerrouki, A., Idiri, Z. and Tobbeche, S., "Natural and Artificial Radioactivity Levels in Sediments in Algiers Bay", Applied Radiation and Isotopes, 48, 1161–1164, 1997.

Beretka, J. and Mathew, P.J., "Natural Radioactivity of Australian Building Materials, Industrial Wastes and By-Products", Health Physics, 48, 87–95, 1985.

Dawood, Y.H., "Factor Controlling Uranium and Thorium Isotopic Composition of the Streambed Sediments of the River Nile, Egypt", JAKU: Earth Science, 21, 77–103, 2010.

El-Gamal, A., Nasr, S., El-Taher, A., "Study of the Spatial Distribution of Natural Radioactivity in Upper Egypt Nile River Sediment", Radiation Measurements, 42, 457–465, 2007.

El-Mamoney, M.H. and Khater, A.E.M., "Environmental Characterization and Radioecological Impacts of Non-Nuclear Industries on the Red Sea Coast", Journal of Environmental Radioactivity, 73, 151–168, 2004.

European Commission, "Radiological Protection Principles Concerning the Natural Radioactivity of Building Materials. Directorate General Environment, Nuclear Safety and Civil Protection", EC Radiation Protection, 112, 1999.

GENIE-2000 Basic Spectroscopy (Standalone) V1.2A Copyright (c), Canberra Industries, 1997.

Issa, S.A.M., Uosif, M.A.M. and Abd el-Salam, L.M., "Natural Radionuclide Concentrations in Granite Rocks in Aswan and Central-Southern Eastern Desert, Egypt and Their Radiological Implications", Radiation Protection Dosimetry, 150, 488–495, 2012.

Kurnaz, A., Küçükömeroglu, B., Keser, R., Okumusoglu, N.T., Korkmaz, F., Karahan, G. and Çevik, U., "Determination of Radioactivity Levels and Hazards of Soil and Sediment Samples in Fırtına Valley (Rize, Turkey)", Applied Radiation and Isotopes, 65, 1281–1289, 2007.

Lozano, J.C., Blanco Rodriguez, P. and Vera Tomé, F., "Distribution of Long-Lived Radionuclides of the ^{238}U Series in the Sediments of a Small River in a Uranium Mineralized Region of Spain", Journal of Environmental Radioactivity, 63, 153–171, 2002.

Mamont-Ciesla, K., Gwiazdowski, B., Biernacka, M. and Zak, A., "Radioactivity of Building Materials in Poland", Natural Radiation Environment (Vohra, G., Pillai, K.C., Sadavisan, S., Eds.). Halsted Press, New York, p. 551, 1982.

Örgün, Y., Altınsoy, N., Şahin, S.Y., Güngör, Y., Gültekin, A.H., Karahan, G. and Karacık, Z., "Natural and Anthropogenic Radionuclides in Rocks and Beach Sands from Ezine Region (Çanakkale), Western Anatolia, Turkey", Applied Radiation and Isotopes, 65, 739–747, 2007.

Papaefthymiou, H., Papatheodorou, G., Moustakli, A., Christodoulou, D. and Geraga, M., "Natural Radionuclides and ^{137}Cs Distributions and their Relationship with Sedimentological Processes in Patras Harbour, Greece", Journal of Environmental Radioactivity, 94, 55–74, 2007.

Ramasamy, V., Suresh, G., Meenakshisundaram, V. and Ponnusamy, V., "Horizontal and Vertical Characterization of Radionuclides and Minerals in River Sediments", Applied Radiation and Isotopes, 69, 184–195, 2011.

Ravisankar, R., Vanasundari, K., Chandrasekaran, A., Rajalakshmi, A., Suganya, M., Vijayagopal, P. and Meenakshisundaram, V., "Measurement of Natural Radioactivity in Building Materials of Namakkal, Tamil Nadu, India Using Gamma-Ray Spectrometry", Applied Radiation and Isotopes, 70, 699–704, 2012.

Righi, S. and Bruzzi, L., “Natural Radioactivity and Radon Exhalation in Building Materials Used in Italian Dwellings”, Journal of Environmental Radioactivity, 88, 158–170, 2006.

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hindiroglu, S. and Karahan, G., “Radionuclide Concentrations in Soil and Lifetime Cancer Risk Due to the Gamma Radioactivity in Kirklareli, Turkey”, Journal of Environmental Radioactivity, 100, 49–53, 2009.

United Nations Scientific Committee on Effects of Atomic Radiation, “Sources, Effects and Risks of Ionizing Radiation”, UNSCEAR Report, New York, 1988.

United Nations Scientific Committee on Effects of Atomic Radiation, “Sources and Effects of Ionizing Radiation”, UNSCEAR Report, New York, 1993.

United Nations Scientific Committee on Effects of Atomic Radiation, “Exposures from Natural Radiation Sources”, UNSCEAR Report, New York, 2000.

Uosif, M.A.M., “Gamma-Ray Spectroscopic Analysis of Selected Samples from Nile River Sediments in Upper Egypt”, Radiation Protection Dosimetry, 123, 215–220, 2007.